Concepts of Teleoperated Robots

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Abstract: This paper provides basic overview of teleoperated robotic systems and their characteristics. The aim of the paper is not to describe such robotic systems in detail such as suggesting actual hardware and software, but to provide basic information, which has to be considered during the design and usage of such robot. Paper is focused on general description of functionality, characteristics and applications of teleoperated robots. Overview of potential use cases is provided with description of potential downfalls. Means of communication with the robot are discussed and elaborated with respect to reliability and safety. Available types of human to machine interfaces and sensor systems are listed and described considering reliability, safety and quality of control. Especially safety issues are highlighted, because such robots suffer from the involvement of humans in the control scheme. This paper comes to a conclusion that it is of primary importance to consider safety measures and stresses vulnerability of whole system introduced by operator and means of communication. In this paper is further stressed that in case of lost communication teleoperated robot must be able to either safely continue its function or stop. Future research will be focused on improving teleoperation via virtual reality, further improvement of autonomous features leaving operator only to decide which actions to perform and cloud computing.

Keywords: Telerobot applications, Telerobot systems, Safety.

1. INTRODUCTION

Deploying robots for manufacturing and for other uses, is getting more current. Great progress of robot applications outside of manufacturing operations can be expected. Manipulation robots, mobile robots and mobile manipulators are developing in applications of industrial robots, service robots and so on. Because of different tasks which it is possible or advisable to robotize, it is required to consider application of “classical” and specialized robotic systems too. In addition to auxiliary manipulators and automatically functioning robots for robotization are needed robotic systems in which operator directly participates in controlling of a robot, while these may be complex actions of robot during performing complicated tasks (biotechnological robots, remote controlled robots, telerobots). These systems meet problems of “imperfect” (at present restricted) means of contemporary robots control systems in terms of fulfilling complex robot operation control tasks with utilization of sensory and intellectual means of an operator. By engaging of operator to direct robot control arise new opportunities of robotics application, new robot roles and concepts of robots.

Teleoperated robots (telerobots) are applicable in a wide range of tasks where the direct involvement of a person is dangerous or impossible. However, there are also applications where telerobots can improve the quality of performance and provide new means which are tied to the fact that position of operator and place where robot performs its activities are remote. The variety of tasks leads to a wide range of telerobots realizations, their control, communication and sensor systems. Basic sensors of telerobots can include sensors of distance, position, speed, acceleration, visual, touch, force, torque etc. Special sensors are designed for mobile telerobots and for safe robot operation. The used sensors are related to usage purpose of telerobot and determine the concepts of control systems and control strategies [1-4].

Due to the nature of the activities performed by telerobots, it is necessary to achieve high reliability and operation safety. Such a requirement raises demands on choice of system concept and mainly on the sensory and control systems. A basic and universal requirement is to carry out only such activities which cannot endanger people which are in working area of robot or its vicinity. With regard to telerobotic operations, which can be performed with no human in the robot workspace, safety requirements are based on the nature of performed operations, *i.e.*, from operating technology. Operational safety check deals with the potential damage to the robot itself or to devices it works with. In addition to matter of safety there is risk that autonomous and semi-autonomous operations won’t be executed and possibility of low quality of operation as well. From a safety point of view, besides the classic sensor tasks, to provide robot and environment information, it is advisable to acquire robot and surrounding environment predictions. It is necessary to create an environmental model and plan

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the operation of the system. Safety of robot's deployment is specifically monitored for cooperative and service robotic systems [5-7].

The solution of the sensor system influences the operator's "comfort" during the telerobot controlling. It is advantageous to achieve a state where the operator has the most similarly mediated state of the environment where the robot performs the operation and a state of the operation being performed. It could be a system of virtual reality or a widespread reality. However, the risk of "overwhelming" the operator with insignificant information needs to be considered. It is endeavored to achieve so called state of telepresence or tele-existence for the operator. Moreover, risks arising from the participation of the human operator during the robot control, mostly when controlling the critical situations need to be considered. For efficient telerobot control it is needed to decide which sensory information operator needs for his job and to respect reaction time of operator. When designing a system, it is vital to address ergonomic issues and mnemotechnic quality of the system concept and “transfer function” of operator (which is different for each operator). Difference in specific dynamic properties of operator in control loop may result in instability of the system. During that time the irreparable damage to the robot may occur and in a worse case to the environment or to the people around the robot.

It is known that humans primarily use visual information [8] for their activity. For control of telerobot other information is important too. For instance, distance, mutual distance, speed and relative speed of systems. However, in order to perform detailed manipulation operations with teleoperated robot, the force-moment information is fundamental from a certain point of operation. For many telerobot operations, information about the progress of processes and the state of the environment from the audio information is important as well [9]. From this point of view, it is not possible to exclude other "perceptions" of the operator and it is also necessary to adapt the sensor system of the robot itself. When efficiency of telerobot deployment is considered, different perception of real situation in telerobot area (*e.g*. when remotely controlling movement of robot – mobile robot moves but operator doesn't, sensor system cannot give realistic and complex sensation of situation to operator) is kind of a problem. Besides the different ways of obtaining the information from an operating environment, the way of typing controlling commands to the robotic system is also important to reduce the operator's load [10]. Various I / O devices serve for this purpose (From this point of view copying control systems and virtual reality systems are also interesting).

For the group of tasks where telerobots are suitable or necessary, it is also possible to consider the use of autonomous robots. Their sensor equipment and the control system complexity however, is higher compared to telerobot's. The structure of the systems is modified to facilitate the work with the telerobot. Therefore, the routine operations are performed automatically and moreover the load on the operator is reduced. Structure of telerobots allows biotechnical control and autonomous operation which enables routine operations to be executed autonomously and operator controls other operations. Meanwhile control system checks decisions of operator in terms of executability and operation safety, which decreases operator load and increases safety of the system. The use of autonomous robots can be considered as the overall goal. Restrictions on the use of autonomous robots are the systems complexity, reliability and the associated costs.

2. TELEROBOT APPLICATIONS

Areas of telerobot deployment are various and depend on specific conditions of actual application, environment, operator experience, etc. It mainly concerns cases which cannot be fulfilled with other means, while respecting safety requirements of executed task.

The deployment of telerobots is legitimate [11]:

- in unstructured and not repeated tasks
- the work environment cannot be customized for the application of manipulators
- the task requires skillful manipulation, especially eye-hand coordination, but not permanent
- the task requires situation and object recognition
- communication channels allow the required quality of information transmission (bandwidth, acceptable transfer delay)

In technical practice it concerns undetermined conditions of extreme environment where it is required to perform intricate movements, complex operations, complex mounting actions with use of universal tools, equipment and so on.

Despite improvements of control systems and having a complex sensor system, successful deployment of telerobot requires trained operators.

For operator work efficiency, information about the robot position, shoulder position, technology head status, visual system orientation, surrounding objects, etc. should be available. Some information could be expressed by numerical data. This would be demanding for operator in terms of the amount of data he has to process and evaluate, therefore it seems more advantageous to provide the information graphically and combined (utilization of virtual reality systems and systems of extended reality). Further, it is necessary to know the information about the robot's relationship with the environment, the relationship between the technological head and the object, the force-moment effect of the head and manipulated object, the force-moment effect on the operator etc.

Telerobot applications can be found, for example in medicine (chirurgic operations Figure **2**, patient care Figure **1** etc.), telehealth assist technologies for households (teleassist for ill, immobile or seniors) [12], space research, underwater research, underground work, pipeline work, radioactive or hazardous or otherwise dangerous environments, rescue work and accidents (Figure **2**), security activities, manipulation with explosives, explosives and so on. Telerobots are designed as stationary or mobile.

Figure 1: Telerobot RP-VITA from iRobot used in medicine [13].

Figure 2: Chirurgic operation with da Vinci [14].

Figure 3: Mobile robot with remote control capability [15].

Figure 4: Telerobotics for hang-up assessment and removal [16].

Figure 5: Utility power lines maintenance telerobot [17].

Figure 6: Telerobot Karo used for rescue missions [18].

The general telerobot control scheme is shown in Figure **7**, where the OP is the operator, the HMI - interface, the CoS - communication system, the R - telerobot, the SS - sensor system, the CS - control system, the SD – servo-drives, the TS – space of the task, the MP – mobile platform. HMI is looked into in thesis [4].

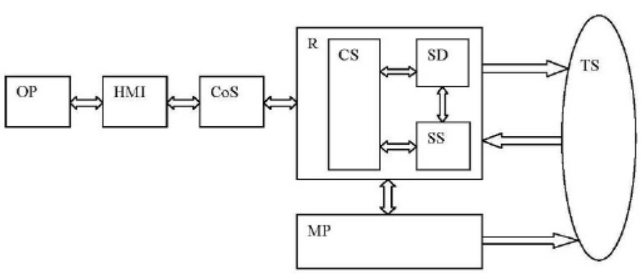

Figure 7: General telerobot control scheme.

3. COMMUNICATION SYSTEM

Telerobots communicate with the operator via contactless lines, in some cases with electric wires or optical fibers. To vital tasks of communication between operator and telerobot system concept design belongs achieving reliable link of required amount of information with required dynamics. During the system construction, it must be assumed that the operation of the system can interrupt the operator's connection to the robot. Necessary requirement is that next activity of the system must be secure even after the interruption of the connection. In addition to controlling the robot's operation after interrupting the connection, it may also be a problem to return the robot to the starting position (it is true especially for mobile systems). After loss of connection control of operation and safety of operation must be provided by local control system of telerobot. Solving issues of telerobot safe operation after loss of connection with operator, protection against hacker attacks, similarly problem of eventual data transfer delay are complicated specific problems. Solving of these problems belongs to important tasks of telerobot deployment.

In recent time, a cloud robotics solution is being developed. Cloud computing can reduce the requirements on the board computing system efficiency, and in the case of groups of robots, the efficiency of operations can be increased. Cloud robotics enables remote computing resource application that provides more memory, higher computational performance, better collective learning, and eventually specific equipment for robotic applications. In the case of cloud solutions for robot control, special attention needs to be paid to the concept of the system in order to ensure safety of the system's operation in the event of a communication failure with the cloud or the event of communication attack. If a robot is unable to operate beyond cloud computing, it can become unhelpful, in the worst case too dangerous.

4. INPUT AND OUTPUT DEVICES

Devices for control information inputting to robot subsystems are needed [4]. To input commands to the control system of telerobot are used various inputting devices. For control of camera system movement, as one of the basic sensor systems, in telerobotics, a wide range of sensors can be considered to control the orientation of the telerobot's camera system. Those are, for example devices for position tracking and devices for operator head orientation which can operate using the magnetic, acoustic, optical or mechanical principles. Cameras can similarly be controlled based on the operator's eye tracking. It is also possible to control the cameras by the detection of the operator’s movement through the visual system. Simple input devices are a touch screen, a graphics tablet, a mouse, a light pen, a touchpad, a TrackPoint, etc. Sensor gloves (fingertip hitting) or whole suits, input manipulators (physical models of robot kinematics, more specifically gloves), 3D mouse, Spaceball, etc. belong to used 3D input devices.

The output devices used to display the information to operator are monitors, 3D glasses, projectors, BOOM (Binocular Omni-Orientation Monitor, Figure **8**), headset display (or helmet-mounted display for air applications, both HMD abbreviations).

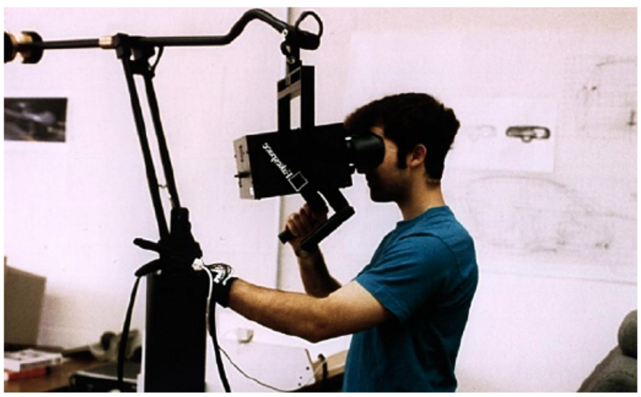

Figure 8: BOOM system [19].

Haptic sensors (Figure **9**), force feedback, joystick, touch feedback, skin feedback (touch, temperature, texture, pressure) are important. For the operator, information about the sounds from the telerobot site's location may also be significant.

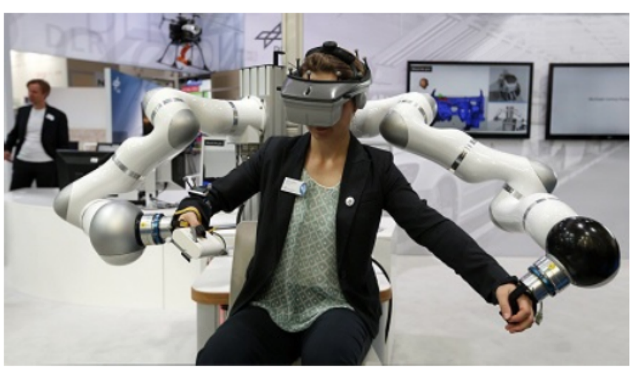

Figure 9: Haptic sensors used for feedback in teleoperated robots [20].

5. SENSORS IN THE SPACE OF TASK

The regular challenge in telerobotics is usually the transport of objects and their positioning with respect to the space or to other objects. All operations can be performed with a certain force or torque, speed, acceleration and accuracy. With an appropriate control system, the operator does not need information from the robot's internal sensors, it uses only information from sensors which are needed in terms of control task. In particular, during the manual control the operator uses visual and tactile information, other information may be considered as supplementary. For successful control of task is important information about distance, mutual distances, speed of movement, and mutual speeds.

Primary feedback for robot control is usually visual feedback. Visual information is the most relevant one and the operator is able to make the most qualified decisions on its basis. Based on evaluation of this information, operator sets additional control targets. Forms of used visual information can be fairly simple - image or signal strength observation. It can be a mono or stereo image. Multiple visual systems may be placed in the space of task. Systems controlled by the movement of the operator's head can be used; other systems that are on the robot’s arm or stationary visual systems may be used as well (placed in space of the task), etc. The image can be edited with different colors, raster light, etc. Used cameras may be sensitive to different parts of the spectrum. Telerobot control has a wide range of visual system utilization. Moreover, A very substantial part of the research deals with the reduction and optimization of data amount sent by robot’s visual systems to the operator of the remote-control place.

Other information may better characterize the situation in the environment, but the operator needs to be trained to properly evaluate it. *E.g*. tactile information is more complex to the operator than visual. The information can be expressed as a force, torque action or as pressure action and so on. The sensors can be placed in the robot wrist, on the robot grip, in the environment where the operation (assembly space) is performed. The operator may have information about the magnitude of the force or torque in numerical form *e.g*. with an extended reality system. More advantageous, but technically more demanding, is a system of reverse torque action on the operator. Where the action on the operator may change with the measurement changes of the acting forces and torques.

Within the extended reality, the operator has the standard information about the distance of the technological head from the object, the distance of robot from the objects in the environment, information about the speed of robot movement and the speed of object movement in the environment, etc.

Special sensors are suitable for mobile telerobotic applications, where besides the motion sensor, sensors for localization and navigation are needed [21-23]. Further information from the sensors require stability control, kinematic structure and telerobot vibration reduction as mobile manipulators do [24, 25].

6. SAFETY

The usual and fully justified requirement for robot's work is operation safety [26, 5-7]. Work must be done in such a way that the robots do not endanger people who could be in workspace of the robot, the surrounding devices or the robot itself. This means that robot's activity must respect both static and dynamic obstacles in the workspace. Telerobot must remain in mode that does not endanger people neither equipment in the environment and will not be damaged if the connection with the operator is lost. Sensor systems make it possible to increase safety of telerobotic applications when inputting control commands by automatically checking the state of the robot and the environment in respect to feasibility and safety.

One way to increase safety is to track the speed and distance between the robot and the obstacle. The robot should decrease its speed when there is an obstacle in the direction of the planned movement in order to safely correct the action when approaching the obstacle.

In the robot construction, it is advisable to achieve a kinematic weight reduction in order to reduce the kinetic energy of the system even in high-speed movements. Simultaneously, it is necessary for the robot to have the necessary stiffness of the kinematic scheme in order to avoid deformations of the kinematic scheme and vibrations during the motion. Achieving of desired movement accuracy along trajectory, positioning and suppressing vibrations of kinematic structure, even with decreased stiffness of kinematic structure is possible with corresponding control of kinematic structure actuator based on information from suitable sensors.

Another requirement is to limit the power and performance of the robot drives so that the set safety value is not exceeded. Such a solution can affect the overall system stiffness and thus the positioning accuracy mainly when forces act on shoulder of robot. Lately increase in work security is achieved by using collaborative robots. There is a technical report by the Robotics Association RIA TR R15.306: 2014 Task-based Risk Assessment Methodology [27] and the new specification ISO / TS 15066: 2016 Robots and robotic devices - Collaborative robots [28] that provide guidance for assessing the risks of collaborative robots, including robots with power and performance limitations, and entire robot systems that, in addition to their own robot, also include effectors, tools, machines and devices in a robotic cell [6].

7. CONCLUSION

With development of robotic systems, utilization of telerobots is also more frequent. Telerobots are being used more and more often, likewise co-operating and service robots. New effective applications are emerging. Remote-controlled robotic systems are allowed to do all the work. Naturally it is tied up to the efficient, secure and reliable computer networks and handy, reliable and safe handling systems that are in most cases mobile. However, such an approach to organizing work is extremely expensive, and therefore telerobotics will continue to be particularly suitable for the applications requiring added layer of safety for the humans such as cleaning of oil storage tanks or searching for disaster victims in rubble, problems requiring better capabilities than humans have for instance for surgery and construction. In this paper was provided simple overview of most important aspects of implementing telerobotics, which enable reader to choose which subsystems are needed for communication, human machine interface and sensors. These subsystems were discussed with respective pros, cons, safety of operation and its significance to telerobotics. The telerobotics development is in the direction of autonomous and semi-autonomous systems development. We strive to implement all these suggestions and most recent knowledge to our own robots. These robots include indoor semiautonomous teleoperated robots equipped with robotic manipulators and laser scanners, outdoor semiautonomous teleoperated robot with GNSS localization system, laser scanner and HDR camera.

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